TOTAL PLANT COSTS

FOR CONTAMINANT FACT SHEETS

See related Fact Sheets: Acronyms & Abbreviations; Cost Assumptions; Glossary of Terms; Raw Water Composition; and WaTER Program.

1. CONTAMINANTS AND TREATMENT PROCESSES

Total plant costs (TPC) are provided for the following groundwater (0 mg/L TSS) treatment processes: direct filtration (DF); reverse osmosis (RO); electrodialysis reversal (EDR); microfiltration (MF); cation and anion ion exchange (IX); softening with lime; and softening with lime and soda ash. TPCs are also provided for the following surface water (13 mg/L TSS) treatment processes: conventional treatment technique (TT); greensand with $KMnO_4$; coagulation and filtration with alum; and coagulation and filtration with ferric sulfate.

! DF is a BAT for asbestos.

! RO is a BAT for: alpha & beta particles (radionuclide); antimony; arsenic; barium; beryllium; copper; cyanide; fluoride; lead; mercury & cadmium; nickel; nitrites & nitrates; radium (radionuclide); selenium; total dissolved solids; trihalomethanes; uranium (radionuclide); and zinc.

! EDR is a BAT for: barium; nitrites & nitrates; selenium; total dissolved solids; and trihalomethanes.

! Cation IX is a BAT for: alkalinity; barium; beryllium; copper; lead; mercury & cadmium; nickel; radium; thallium; and zinc.

! Anion IX is a BAT for: alkalinity; chromium; cyanide; nitrites & nitrates; and uranium.

! Lime softening is a BAT for: alkalinity; barium; beryllium; chromium; copper; lead; mercury & cadmium; nickel; and zinc.

! Lime & soda ash softening is a BAT for: arsenic; radium; selenium; and uranium.

! Conventional TT is a BAT for *Cryptosporidium* & *Giardia*.

! Greensand and $KMnO_4$ is a BAT for iron & manganese.

! Coagulation and filtration with alum is a BAT for: antimony; asbestos; beryllium; chromium; copper; lead; mercury & cadmium; selenium; and uranium.

! Coagulation and filtration with ferric sulfate is a BAT for: arsenic; selenium; and trihalomethanes.

Although MF is not currently a recommended BAT, its versatility and usage is rapidly gaining acceptance in the water treatment industry. Therefore, MF TPCs are included for reference and comparison purposes with other treatment processes.

See the appropriate contaminant fact sheet for specific information on the contaminant and the EPA recommended BAT treatment processes.

2. TOTAL PLANT COSTS

There is a need to be able to compare various treatment processes costs - not only on an individual unit process basis (as done in each contaminant fact sheet), but on a total plant costs basis by amortizing capital equipment and annual O&M costs over time. To help address that need, this total plant costs fact sheet was prepared.

S. R. Qasim, *et al.*, "Estimating Costs for Treatment Plant Construction," *Journal AWWA*, August 1992, state, "Preliminary cost estimates can be used to compare the economics of various treatment processes or the costs of major project components. Such estimates do not, however, represent the actual construction and operation and maintenance costs of the project. Actual project costs are site-specific, cannot be generalized, and must be developed for individual circumstances. Many factors influence the construction costs - plant capacity, design criteria, treatment processes, site conditions and land cost, climate, permit costs, competition among bidders and suppliers, and general local and nationwide economic conditions."

These statements also apply to the individual contaminant fact sheet's BAT capital equipment and annual O&M cost curves, as well as the TPC cost curves presented herein. All TPCs should be considered preliminary cost estimates for comparison purposes only. Secondary cost estimates must be developed during the design process and final cost estimates must be developed prior to construction.

The TPCs were developed using the following information and the assumptions presented on the Cost Assumptions, Raw Water Composition, and WaTER Program related fact sheets. The TPCs include the annualized capital equipment costs for all the unit processes in the BAT treatment train (see the following treatment train schematic diagrams). TPCs also include annual O&M costs, and various project related special costs including special site work, general contractor's overhead & profit, engineering fees, land costs, legal fees, fiscal costs, administrative costs, and interest during construction. The project related special costs are those listed by USEPA in the *Estimating Water Treatment Costs* manual - and are considered more directly related to the total cost of the project than to the cost of the individual unit processes. For this reason, the project related special costs included in the TPCs must be considered even more preliminary than the equipment and O&M costs. Project related special costs can only be developed once a specific site is identified. However, for comparison purposes only, several assumptions and estimates were developed and as many references and sources that could be reasonably be obtained were consulted prior to developing the following project related special costs. These include:

! Special site work is considered site work specific to a particular site rather than a project (i.e., river crossings; earthquake, high wind, or snow loadings, etc.). Because these are so site specific, very few references were found. Therefore, an estimate of 2% of the capital equipment costs was included.

! General contractor's overhead & profit can include project and business overhead, profit, and bonds. Historical data from several Reclamation projects indicate a range from 14.5 - 32.5% of the capital equipment costs. The Construction Specification Institute (CSI) suggests 10 - 15% of the direct costs. Two A&E firms in the Denver area suggest 25 - 33%. Therefore, an estimate of 20% of the capital equipment costs was included.

! Engineering fees include those charged by A&E firms. The Means 2001 Cost Data estimates 2.5 - 6%. CSI suggests 19.5 - 23.9% of the direct costs. Two A&E firms in the Denver area suggest 10%. Irving Moch, Jr., Moch & Associates, Inc., suggests 10%. Therefore, an estimate of 10% of the capital equipment costs was included.

! Land costs are very site specific. Historical data from several Reclamation projects indicate a range from $500 - $10,000/acre. Therefore, an estimate of $2,500/acre for 5 acres was included.

! No references were found for legal fees and fiscal costs. Therefore, an estimate of 1% of the capital equipment costs was included.

! Administrative costs can include construction and administrative management/oversight. Means 2001 Cost Data estimates 4.5 - 7.5% for job values to $1,000,000 and 2.5 - 4% for job values to $5,000,000. Therefore, an estimate of 5% of the capital equipment costs was included.

! Interest during construction is very project specific. Irving Moch suggests 2 - 5%. Information from Reclamation's economics group suggests 3 - 4% for a 1 year loan when payments are equally spaced. Therefore, an estimate of 3% of the capital equipment costs was included.

All project related special costs totaled 41% plus $12,500 for land ($2,500/acre at 5 acres).

Following are the equations used to develop the TPCs:

! Annualized capital cost = [(total capital equipment costs for all treatment train unit processes) + (project related special costs)] x capital recovery factor for 30 years at 3.89% real annual interest based on no lagged impact on interest = 0.057.

! Total annual cost = (annualized capital costs) + (total annual O&M costs for all treatment train unit processes).

! TPC in $/1000 gal of water produced = (total annual cost) / annual flow.

3. RO TPC

Process - RO is a physical process in which contaminants are removed by applying pressure on the feed water to direct it through a semipermeable membrane. The process is the "reverse" of natural osmosis (water diffusion from dilute to concentrated through a semipermeable membrane to equalize ion concentration) as a result of the applied pressure to the concentrated side of the membrane, which overcomes the natural osmotic pressure. RO membranes reject ions based on size and electrical charge. The raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Common RO membrane materials include asymmetric cellulose acetate or polyamide thin film composite. Common membrane construction includes spiral wound or hollow fine fiber. Each material and construction method has specific benefits and limitations depending upon the raw water characteristics and pretreatment. A typical large RO installation includes a high pressure feed pump, parallel 1st and 2nd stage membrane elements (in pressure vessels); valving; and feed, permeate, and concentrate piping. All materials and construction methods require regular maintenance. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Factors influencing performance are raw water characteristics, pressure, temperature, and regular monitoring and maintenance. The conventional RO treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an antiscalant, slow mix flocculator, sedimentation basin or clarifier, gravity filters, RO membranes, chlorine disinfection, and clearwell storage. MF could be used in place of flocculation, sedimentation, and filtration.

Pretreatment - RO requires a careful review of raw water characteristics and pretreatment needs to prevent membranes from fouling, scaling, or other membrane degradation. Removal of suspended solids is necessary to prevent colloidal and bio-fouling, and removal of dissolved solids is necessary to prevent scaling and chemical attack. Large installation pretreatment can include media filters to remove suspended particles; ion exchange softening or antiscalant to remove hardness; temperature and pH adjustment to maintain efficiency; acid to prevent scaling and membrane damage; activated carbon or bisulfite to remove chlorine (postdisinfection may be required); and cartridge (micro) filters to remove some dissolved particles and any remaining suspended particles.

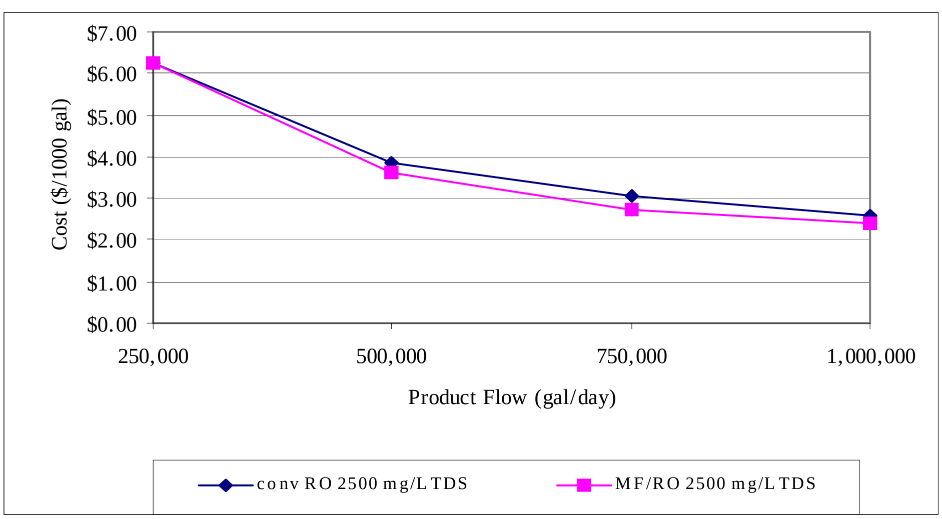
Maintenance - Monitor rejection percentage to ensure contaminant removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly flushed through the system at high volume/low pressure with a cleaning agent to remove fouling and scaling. The system is flushed and returned to service. $NaHSO_3$ is a typical caustic cleaner. RO stages are cleaned sequentially. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

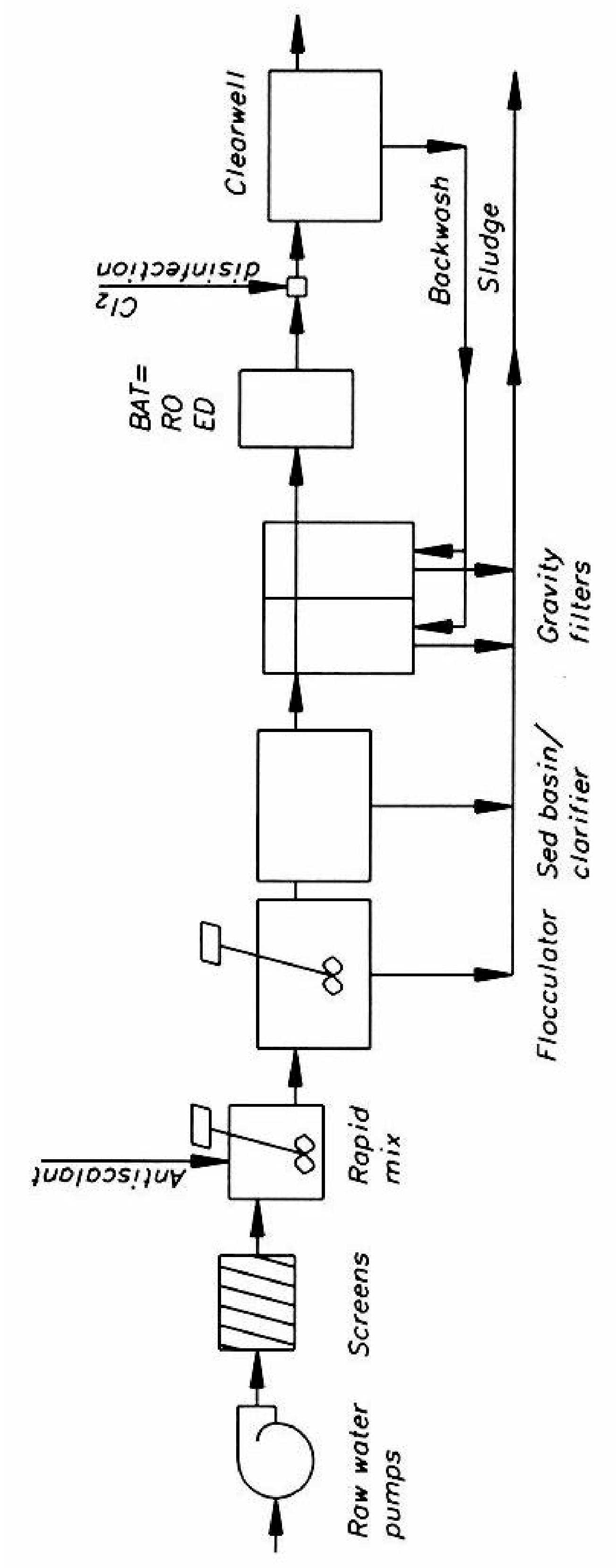
Waste Disposal - Pretreatment waste streams, concentrate flows, and spent filters and membrane elements all require approved disposal.

Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Sb removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

TPC - $/1000 gal




Raw water pumps
Screens
Antiscalant
Rapid mix
Flocculator
Sed basin/ clarifier
Gravity filters
BAT=
RO
ED
Cl_2 disinfection
Clearwell
Backwash
Sludge

4. EDR TPC

Process - EDR is an electrochemical process in which ions migrate through ion-selective semipermeable membranes as a result of their attraction to two electrically charged electrodes. A typical EDR system includes a membrane stack with a number of cell pairs, each consisting of a cation transfer membrane, a demineralized flow spacer, an anion transfer membrane, and a concentrate flow spacer. Electrode compartments are at opposite ends of the stack. The influent feed water (chemically treated to prevent precipitation) and concentrated reject flow in parallel across the membranes and through the demineralized and concentrate flow spacers, respectively. The electrodes are continually flushed to reduce fouling or scaling. Careful consideration of flush feed water is required. Typically, the membranes are cation- or anion-exchange resins cast in sheet form; the spacers are HDPE; and the electrodes are inert metal. EDR stacks are tank contained and often staged. Membrane selection is based on careful review of raw water characteristics. A single-stage EDR system usually removes 50 percent of the TDS; therefore, for water with more than 1000 mg/L TDS, blending with higher quality water or a second stage is required to meet 500 mg/L TDS. EDR uses the technique of regularly reversing the polarity of the electrodes, thereby freeing accumulated ions on the membrane surface. This process requires additional plumbing and electrical controls, but increases membrane life, does not require added chemicals, and eases cleaning. The conventional EDR treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an antiscalant, slow mix flocculator, sedimentation basin or clarifier, gravity filters, EDR membranes, chlorine disinfection, and clearwell storage. MF could be used in place of flocculation, sedimentation, and filtration.

Pretreatment - Guidelines are available on accepted limits on pH, organics, turbidity, and other raw water characteristics. Typically requires chemical feed to prevent scaling, acid addition for pH adjustment, and a cartridge filter for prefiltration.

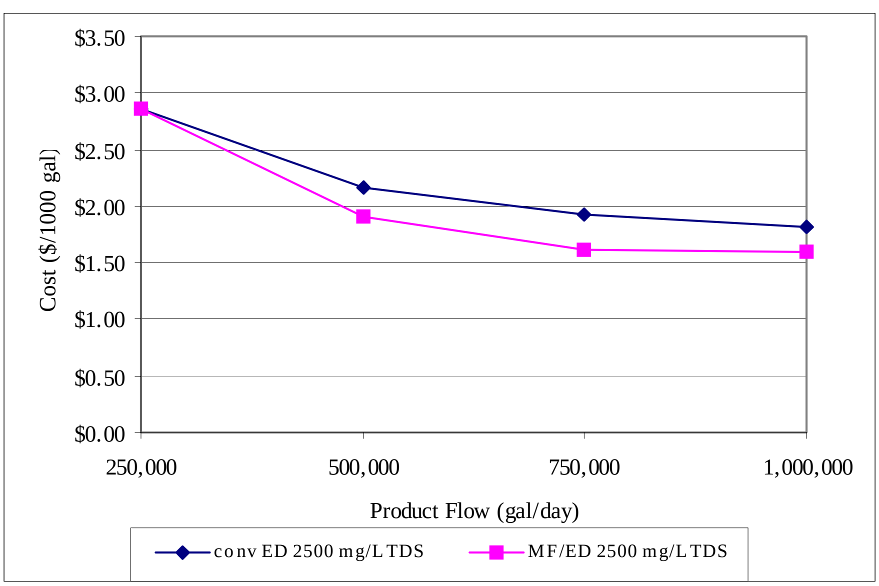
Maintenance - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode reaction. The byproducts are hydrogen, formed in the cathode space, and oxygen and chlorine gas, formed in the anode spacer. If the chlorine is not removed, toxic chlorine gas may form. Depending on raw water characteristics and Ba concentration, the membranes will require regular maintenance or replacement. EDR requires reversing the polarity. Flushing at high volume/low pressure continuously required to clean electrodes. If utilized, pretreatment filter replacement and backwashing will be required. The EDR stack must be disassembled, mechanically cleaned, and reassembled at regular intervals.

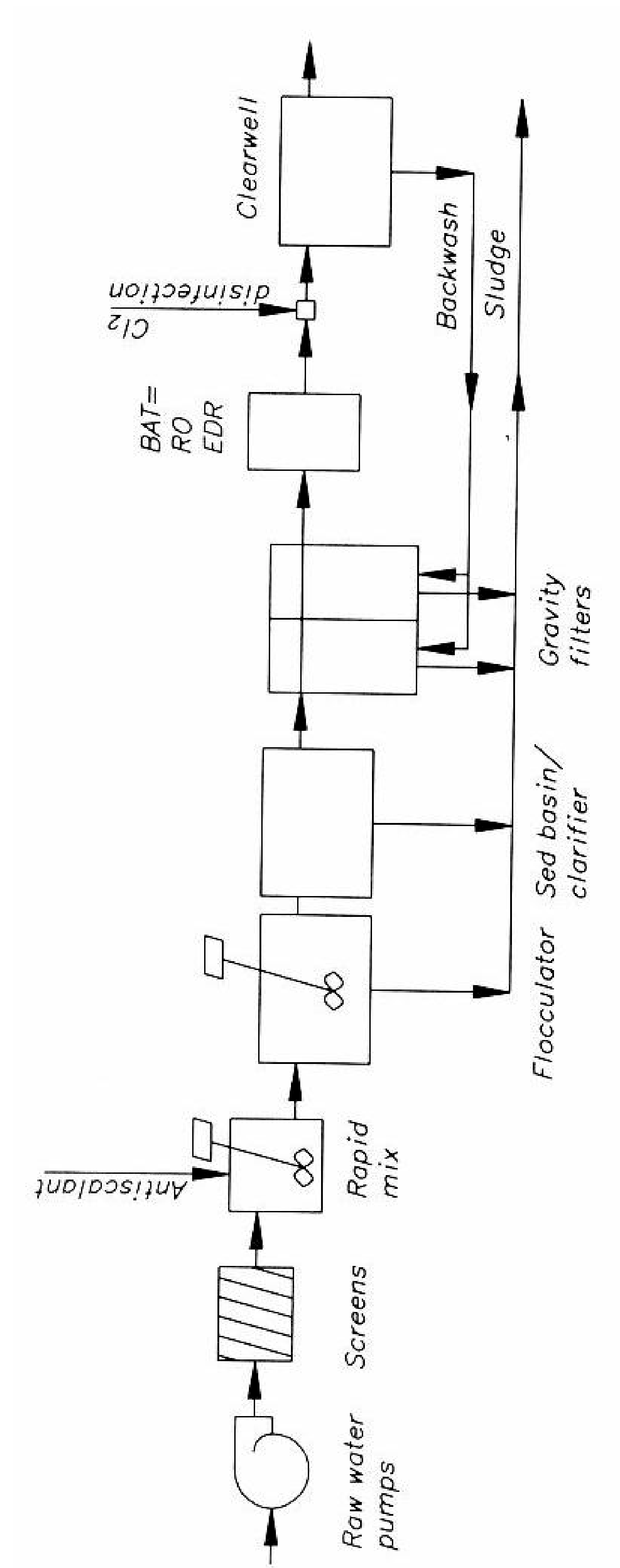
Waste Disposal - Highly concentrated reject flows, electrode cleaning flows, and spent membranes require approved disposal. Pretreatment processes and spent materials also require approved disposal.

Advantages -
- ! EDR can operate with minimal fouling or scaling, or chemical addition.
- ! Low pressure requirements; typically quieter than RO.
- ! Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

Disadvantages -
- ! Not suitable for high levels of Fe and Mn, H_2S, chlorine, or hardness.
- ! Limited current density; current leakage; back diffusion.
- ! At 50% rejection of TDS per pass, process favors low TDS water.

TPC - $/1000 gal




Raw water pumps
Screens
Antiscalant
Rapid mix
Flocculator
Sed basin/ clarifier
Gravity filters
BAT= RO EDR
Cl_2 disinfection
Clearwell
Backwash
Sludge

5. IX TPC

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in ions is obtained. Operation begins with a fully recharged cation or anion resin bed, having enough positively or negatively charged ions to carry out the cation or anion exchange. Usually a polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the positively or negatively charged ions are released into the water, being substituted or replaced with the contaminant ions in the water (ion exchange). When the resin becomes exhausted of positively or negatively charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the contaminant ions with Na or K ions. Many different types ofresins can be used to reduce dissolved contaminant concentrations. Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-contaminant is greater than 1. The IX treatment train typically includes raw water pumps, debris screens, gravity filters, cation or anion resin beds, chlorine disinfection, and clearwell storage.

Pretreatment - Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics. Pretreatment may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration.

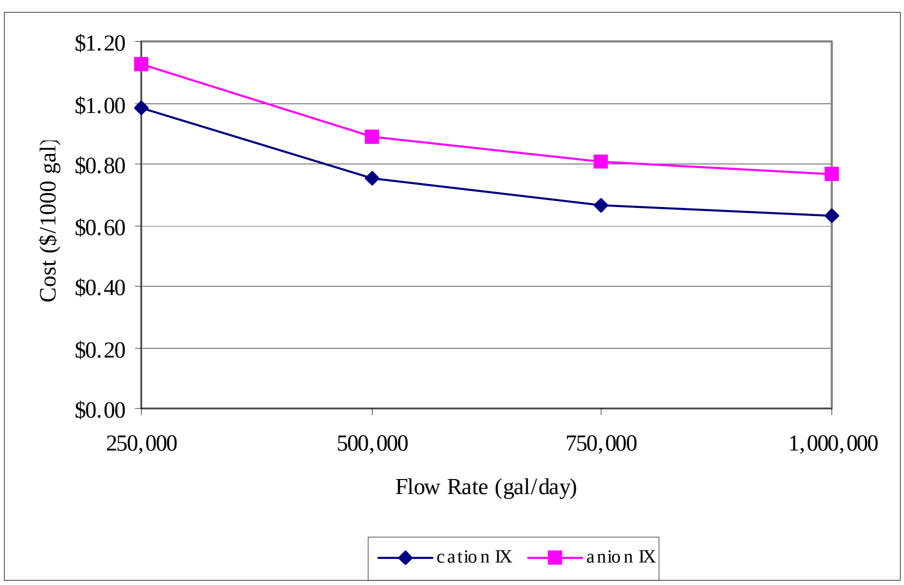
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the contaminant concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

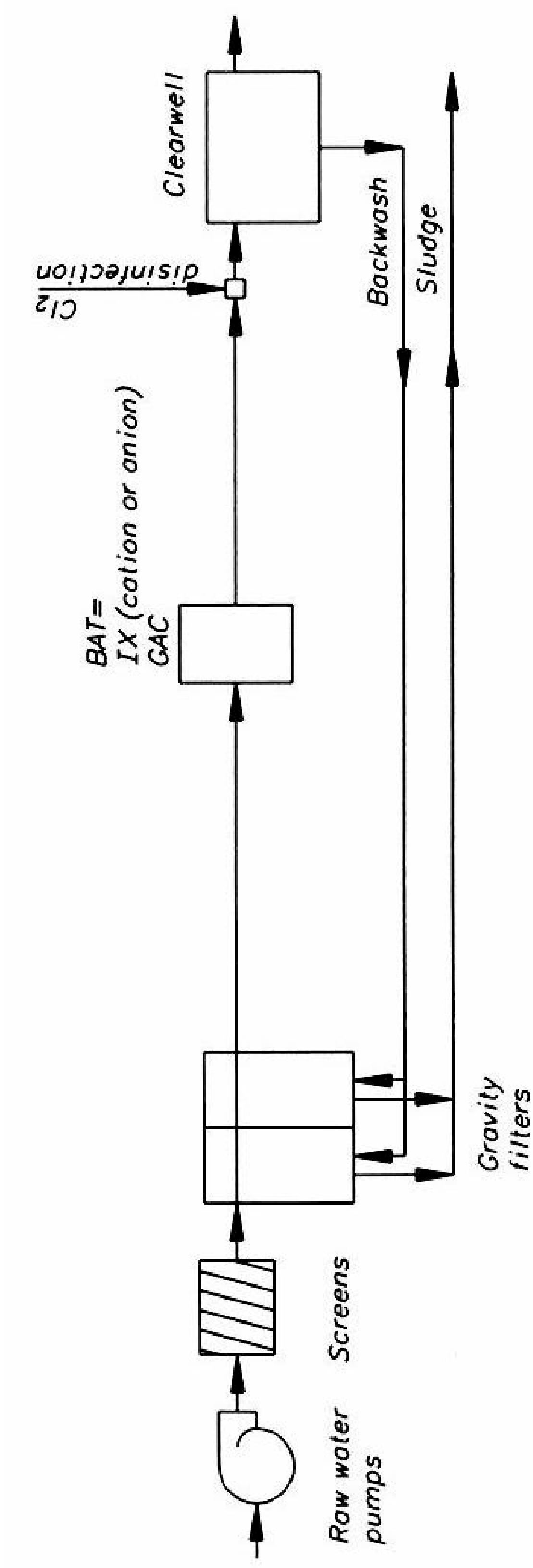
Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline solution); occasional solid wastes (in the form of broken resin beads) which are backwashed during regeneration; and if utilized, spent filters and backwash waste water.

Advantages -
- Acid addition, degasification, and repressurization is not required.
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

TPC - $/1000 gal




Raw water pumps
Screens
Gravity filters
BAT=
IX (cation or anion)
GAC
Cl2
disinfection
Clearwell
Backwash
Sludge

6. SOFTENING TPC

Process - Lime softening uses a chemical addition followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical additions include adding (1) $Ca(OH)_2$ in sufficient quantity to raise the pH while keeping the levels relatively low to precipitate CO_3^{-2} hardness or (2) $Ca(OH)_2$ to precipitate carbonate and Na_2CO_3 to precipitate noncarbonate hardness. The contaminant precipitates as sludge. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material into larger particles) and final clarification occur. The clarified water flows up and over the weirs, while the settled particles are removed by pumping or other collection mechanisms (i.e. filtration). The softening treatment train typically includes raw water pumps, debris screens, addition of $Ca(OH)_2$ or $Ca(OH)_2$ & Na_2CO_3 at an upflow SCC, gravity filters, chlorine disinfection, and clearwell storage.

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required. Optimum pH is about 10 for $Ca(OH)_2$ and about 10.5 or higher for $Ca(OH)_2$ and Na_2CO_3.

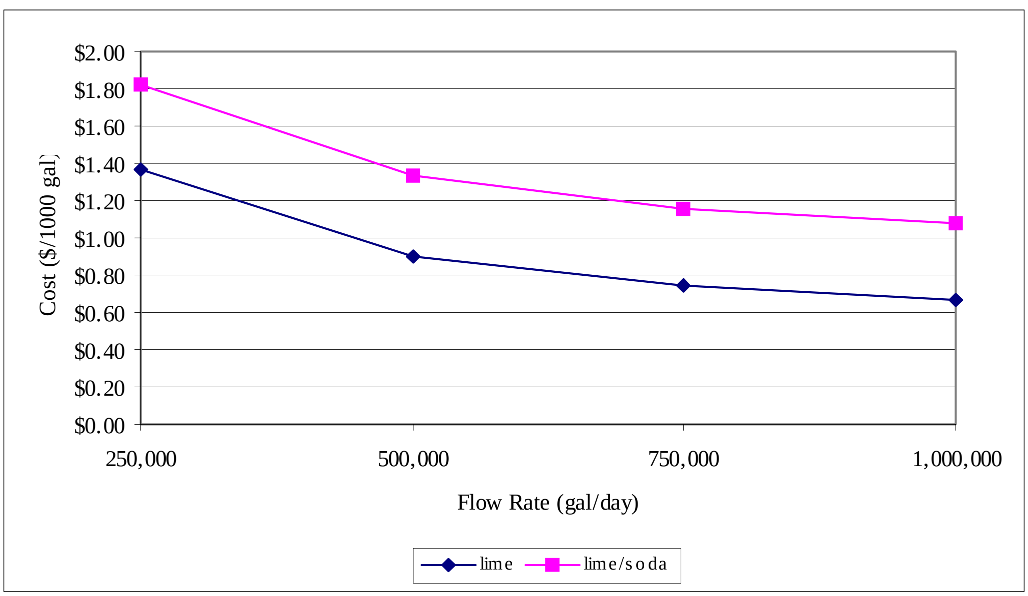
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Similar procedures also apply to the sludge disposal return system, which takes the settled sludge from the bottom of the clarifier and conveys it to the dewatering and disposal processes.

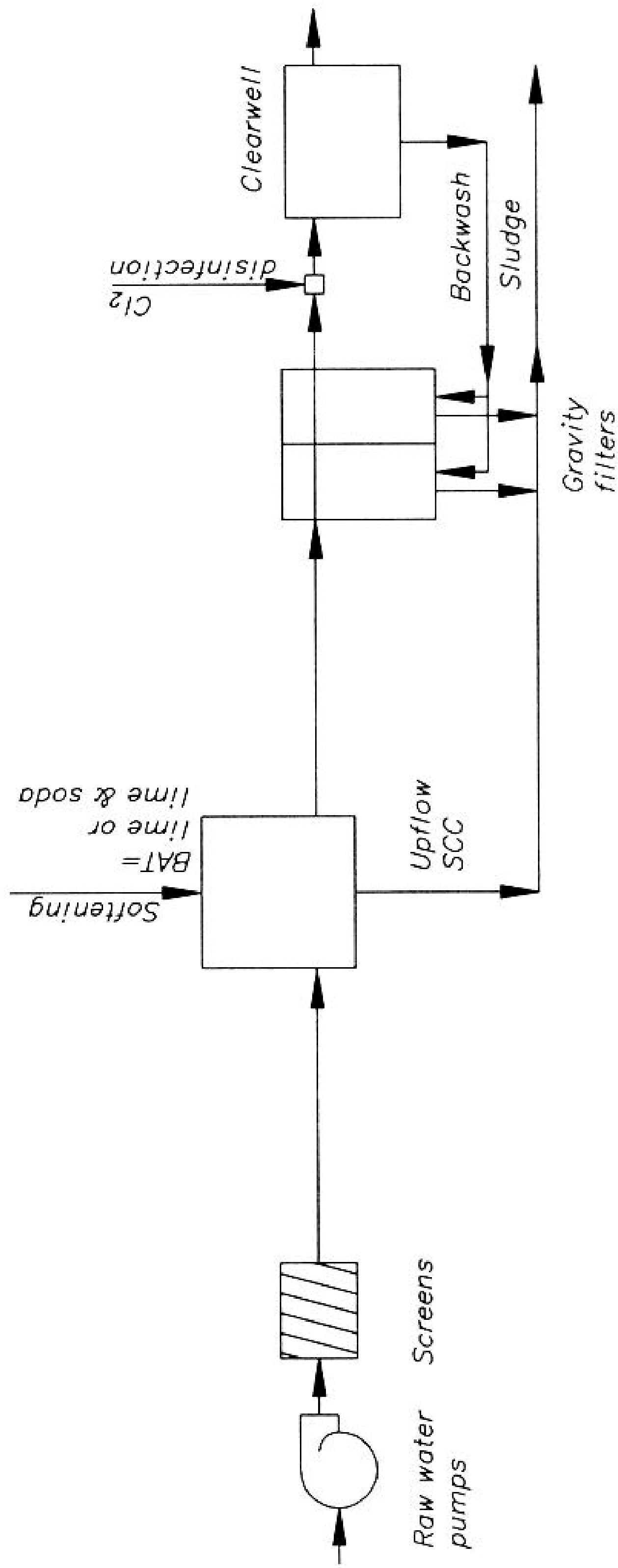
Waste Disposal - There are three disposal options for softening sludges: incineration, landfill, and ocean disposal.

Advantages -
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- Produces high sludge volume.
- Secondary treatment may be required.
- Waters high in sulfate may cause significant interference with removal efficiencies.

TPC - $/1000 gal




Raw water pumps
Screens
Softening
BAT= lime or lime & soda
Upflow SCC
Gravity filters
Cl_2 disinfection
Backwash
Sludge
Clearwell

7. CONVENTIONAL TT TPC

Process - For community surface and groundwater (under the direct influence of surface water) systems, conventional treatment techniques, including presedimentation or screening, chemical coagulation and flocculation, final settling or clarification, filtration, and disinfection ensure protection of both surface and groundwaters prior to entering distribution systems. These TTs work to remove and inactivate pathogens before they enter the distribution system. Not all processes are required in every case, so actual process selection depends on careful review of overall raw water quality and characteristics. Presedimentation or screening consists of removing the largest/heaviest suspended solids from the raw water. Chemical coagulation and flocculation consists of adding a chemical coagulant ($Al_2(SO_4)_3$ and polymer) combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). Costs presented below include alum (230 ppm) as the coagulant, rapid mix for 30 seconds, and flocculation for 30 minutes. Final settling or clarification consists of settling of the floc matter. Filtration consists of final removal by dual media filtering (or membrane) of all floc; suspended; and, based on filtration method/size, most dissolved solids, including pathogens. These TTs result in lowering overall TSS/TDS and turbidity, which in turn allows greater disinfection contact time on remaining pathogens. Disinfection consists of chemical inactivation (killing) of pathogens, bacteria, and viruses, usually by chlorination. As a result of crypto/giardia occurrences, investigations into the effectiveness of various water treatment processes for oocyst/cyst removal/inactivation are continuing. In addition to the unit processes mentioned, the conventional TT treatment train typically includes raw water pumps, debris screens, and clearwell storage.

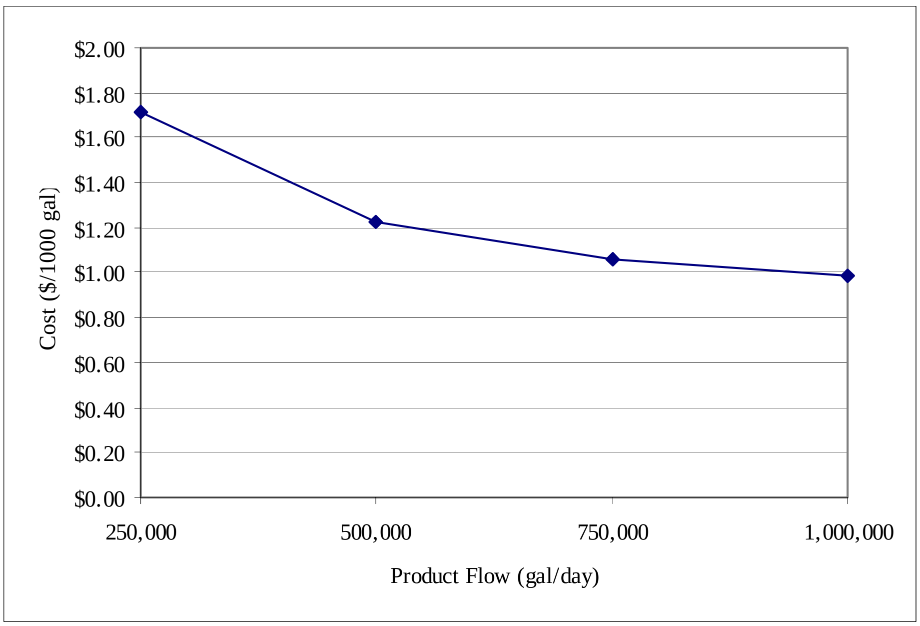
Maintenance - Proper monitoring, operation, and maintenance procedures, especially of the final filter, are essential to ensure the reliability of these TT processes. Recycled filter backwash or membrane cleaning methods may concentrate oocyst/cysts and result in a significant source of increased turbidity and crypto/giardia infestation. As a result, a period of filter-to-waste flow may be required after post-backwash/membrane cleaning periods. Because turbidity removal can parallel oocyst/cyst removal, finished water turbidity monitoring (<0.5 NTU) may be a useful tool for indicating the degree of pathogen removal. Depending on filtration process, recharging or clean installation of media is required.

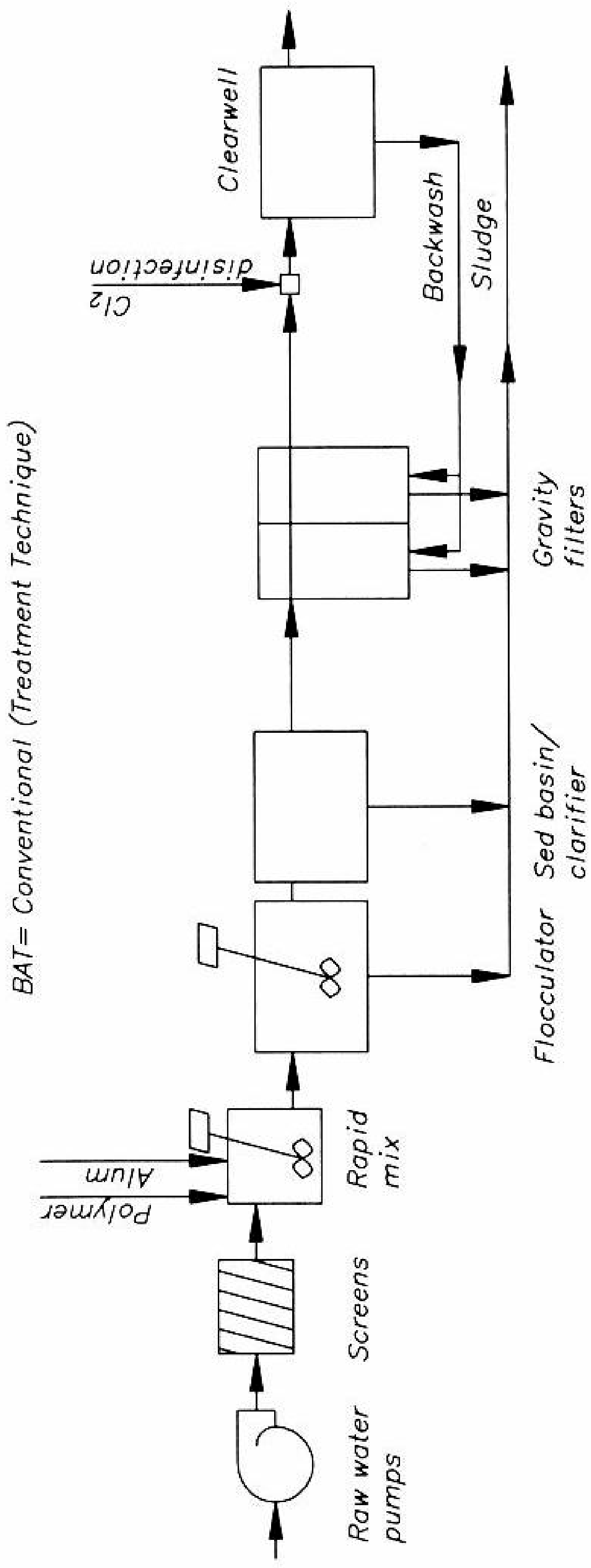
Waste Disposal - Pretreatment waste streams and spent filters or filter material require approved disposal.

Advantages -
- Well established and reliable.
- Low operator requirements.

Disadvantages -
- Costly initial investment and land intensive.
- Lack of accepted testing and monitoring techniques may cause confusion.

TPC - $/1000 gal




BAT= Conventional (Treatment Technique)
Raw water pumps
Screens
Polymer
Alum
Rapid mix
Flocculator
Sed basin/ clarifier
Gravity filters
Cl_2 disinfection
Clearwell
Backwash
Sludge

8. GREENSAND & $KMnO_4$ TPC

Process - Oxidation is a chemical process and filtration is a physical process. $KMnO_4$ is added to the raw water which oxidizes the soluble Fe and Mn into insoluble ferric and manganic oxides which will settle and are filterable. $KMnO_4$ (without prechlorination) is usually used according to the following stoichiometry:

0.94 mg/L $KMnO_4$ per mg/L of Fe^{+2} removed and
1.92 mg/L $KMnO_4$ per mg/L of Mn^{+2} removed.

After the oxidation process is complete, the greensand filter removes the insoluble material. Greensand is a green clay material whose active mineral is glauconite, a natural zeolite with ion exchange properties. Greensand is layered loosely to form the media bed. As water passes through the filter, any remaining soluble Fe and Mn are pulled from the solution by the ion exchange properties of the greensand, and the insoluble Fe and Mn are filtered by the greensand media. Periodically, the greensand media is regenerated by continually feeding $KMnO_4$ just before the filter to recharge the glauconite, regenerating the ion exchange properties. Additionally, periodic backwashing of the filter media to remove the Fe and Mn is required. The greensand and $KMnO_4$ treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an polymer, slow mix flocculator, sedimentation basin or clarifier, greensand filters with $KMnO_4$ addition, chlorine disinfection, and clearwell storage.

Pretreatment - Feeding chlorine ahead of the $KMnO_4$ can make the process more economical. $Ca(OH)_2$ addition may be necessary to achieve the desired pH level or to remove CO_2.

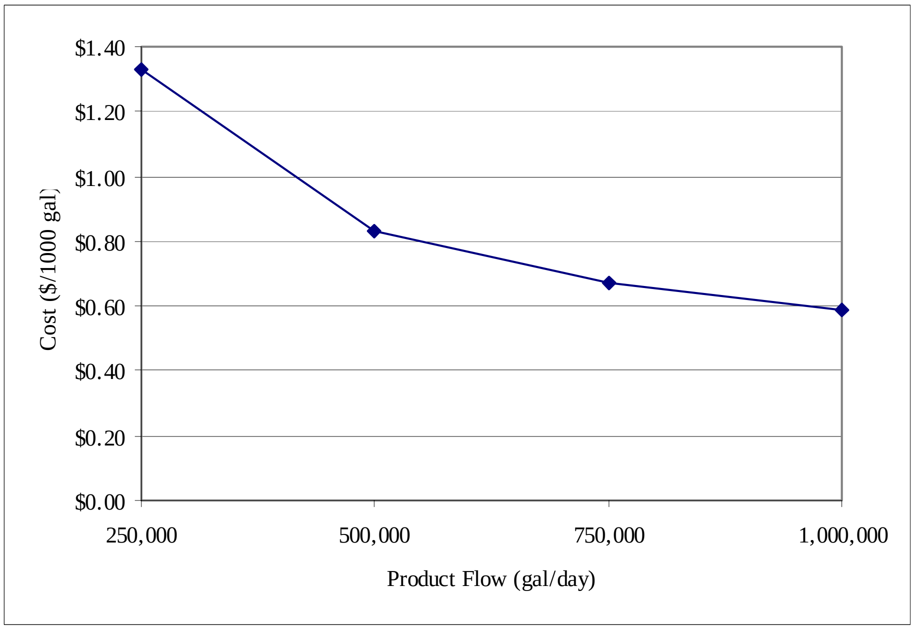
Maintenance - Tests should be conducted at least monthly on samples of the water entering the filter to ensure the contaminants are in their insoluble oxidized states and to verify $KMnO_4$ dosages. Regeneration and backwashing should be done in accordance with the greensand media manufacturer's recommendations. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

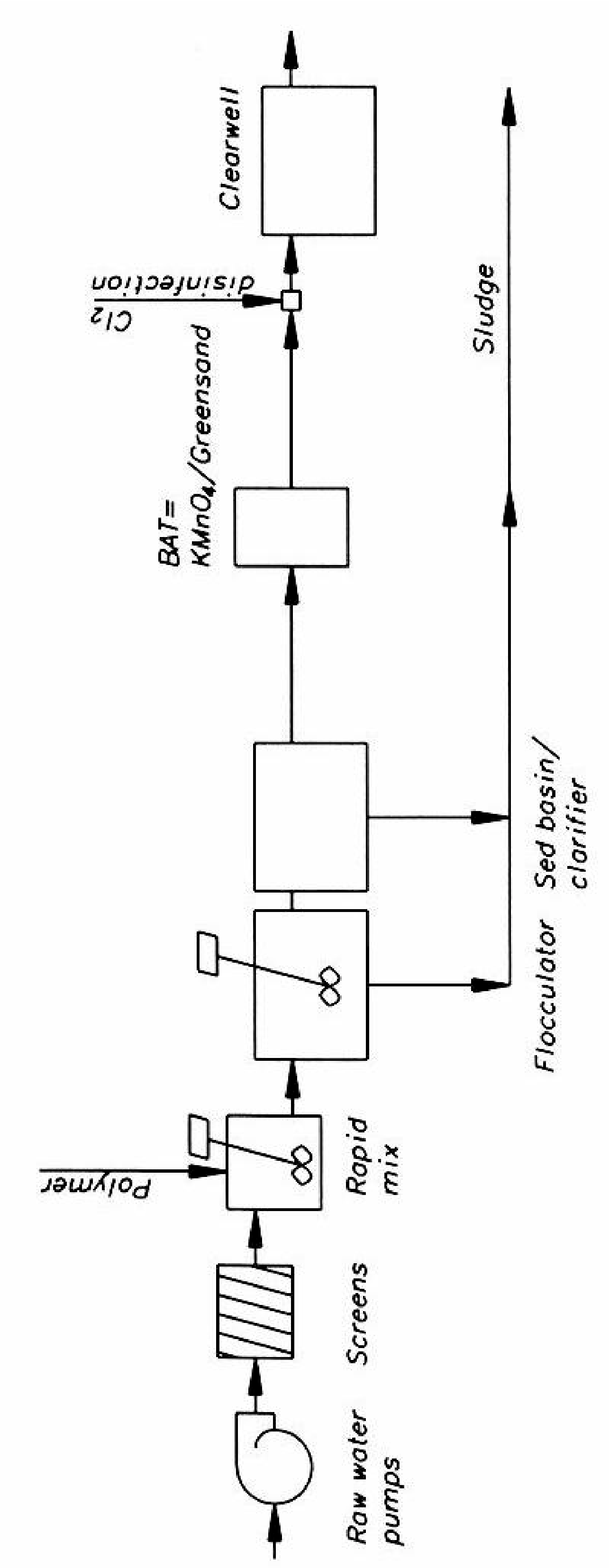
Waste Disposal - Filter regeneration and backwash waters, and spent media require approved disposal.

Advantages -
- Low cost.
- Efficient; proven; reliable.

Disadvantages -
- $KMnO_4$ dosage must be exact; bench scale tests are required to determine exact dosage; monitoring of performance to ensure proper dosage.
- Sufficient pressure and flowrate required for backwashing; backwash disposal required.
- Regeneration required; regeneration disposal required.

TPC - $/1000 gal




Raw water pumps
Screens
Polymer
Rapid mix
Flocculator
Sed basin/ clarifier
BAT= $KMnO_4$/Greensand
Cl_2 disinfection
Clearwell
Sludge

9. COAGULATION & FILTRATION TPC

Process - Coagulation and filtration uses the conventional chemical and physical treatment processes of chemical addition, rapid mix, coagulation with dry alum, flocculation, and dual media filtration. Chemical coagulation and flocculation consists of adding a chemical coagulant combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). Depending on the contaminant, either $Al_2(SO_4)_3$ or $Fe_2(SO_4)_3$ can be the most effective coagulant. Filtration provides final removal by dual media filtering of all floc and suspended solids. In addition to the unit processes mentioned, the coagulation and filtration treatment train typically includes raw water pumps, debris screens, sedimentation, chlorine disinfection, and clearwell storage.

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required.

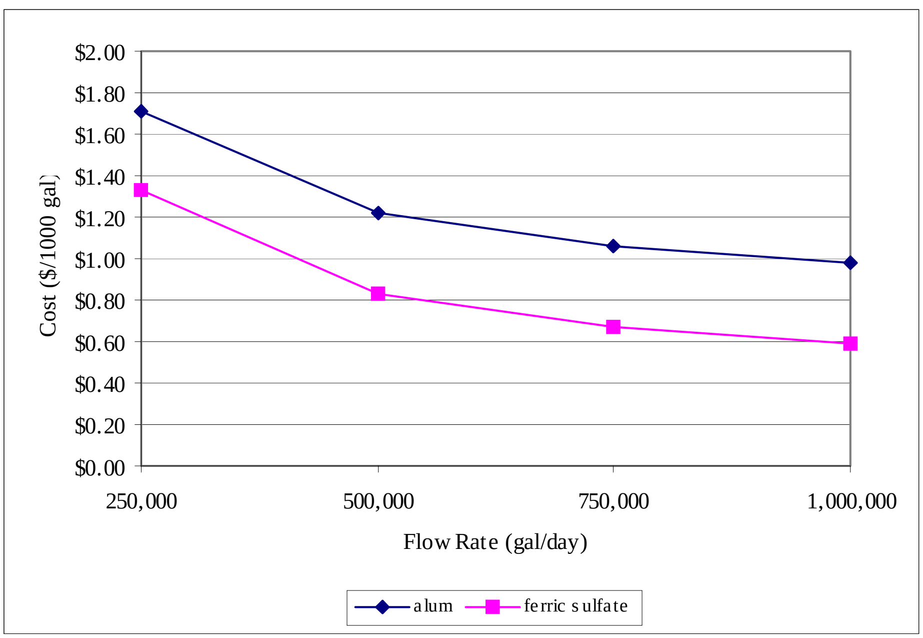
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Routine checks of contaminant buildup in the filter is required, as well as filter backwash. Recharging or clean installation of media is periodically required.

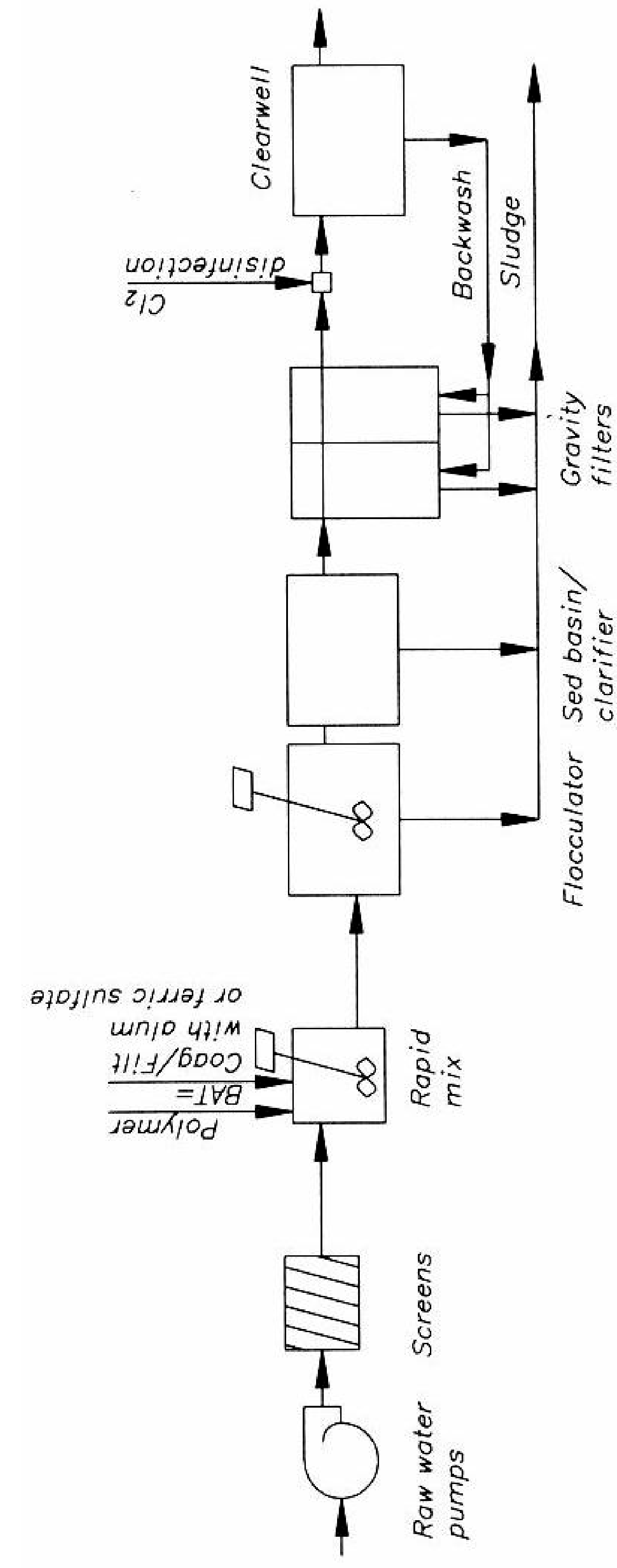
Waste Disposal - Filter backwash and spent material require approved disposal.

Advantages -
- ! Lowest capital costs.
- ! Lowest overall operating costs.
- ! Proven and reliable.
- ! Low pretreatment requirements.

Disadvantages -
- ! Operator care required with chemical handling.
- ! Produces high sludge volume.
- ! Waters high in sulfate may cause significant interference with removal efficiencies.

TPC - $/1000 gal




Raw water pumps
Screens
Polymer
BAT= Coag/Filt with alum or ferric sulfate
Rapid mix
Flocculator
Sed basin/ clarifier
Gravity filters
Cl2 disinfection
Clearwell
Backwash
Sludge

10. GAC TPC

Process - GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the highly porous media which has an extremely high surface area for adsorption, the dissolved contaminants adsorb on the solid surface. GAC is made of tiny clusters of carbon atoms stacked upon one another. The carbon media is produced by heating the carbon source (generally activated charcoal) in the absence of air to produce a high carbon material. The carbon media is activated by passing oxidizing gases through the material at extremely high temperatures. The activation process produces the pores that result in such high adsorption properties. The adsorption process depends on the following factors: 1) physical properties of the GAC, such as type of raw carbon, method of activation, pore size distribution, and surface area; 2) the chemical/electrical nature of the carbon source or method of activation, and the amount of oxygen and hydrogen associated with them, such that as the carbon surfaces become filled the more actively adsorbed contaminants will displace the less actively adsorbed ones; 3) chemical composition and concentration of contaminants, such as size, similarity, and concentration, affect adsorption; 4) the temperature and pH of the water, in that adsorption usually increases as temperature and pH decreases; and 5) the flowrate and exposure time to the GAC, in that low contaminant concentration and flowrate with extended contact times increase the carbon's life. GAC devices include: pour-through for treating small volumes; faucet-mounted (with or without by-pass) for single point use; in-line (with or without by-pass) for treating large volumes at several faucets; and high-volume commercial units for treating community water supply systems. Careful selection of type of carbon to be used is based on the contaminants in the water and manufacturer's recommendations. The GAC treatment train typically includes raw water pumps, debris screens, gravity filters, GAC units, chlorine disinfection, and clearwell storage.

Pretreatment - With bacterially unstable waters, filtration and disinfection prior to carbon treatment may be required. With high TSS waters, prefiltration may be required.

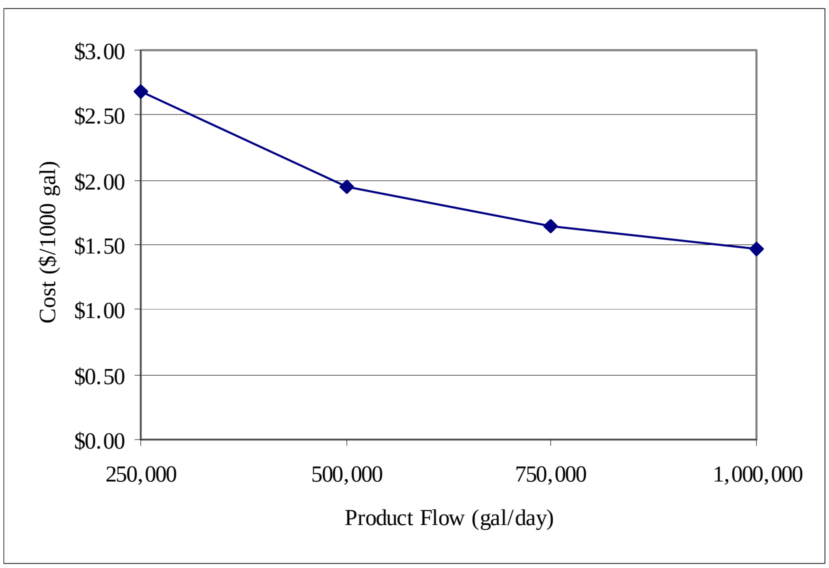
Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used. The manufacturer's recommendations for media replacement should be consulted. Recharging by backwashing or flushing with hot water (145^{o}F) may release the adsorbed chemicals, however this claim is inconclusive. With bacterially unstable waters, monitoring for bacterial growth is required because the adsorbed organic chemicals are a food source for some bacteria. Flushing is required if the carbon filter is not used for several days, and regular backwashing may be required to prevent bacterial growth. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

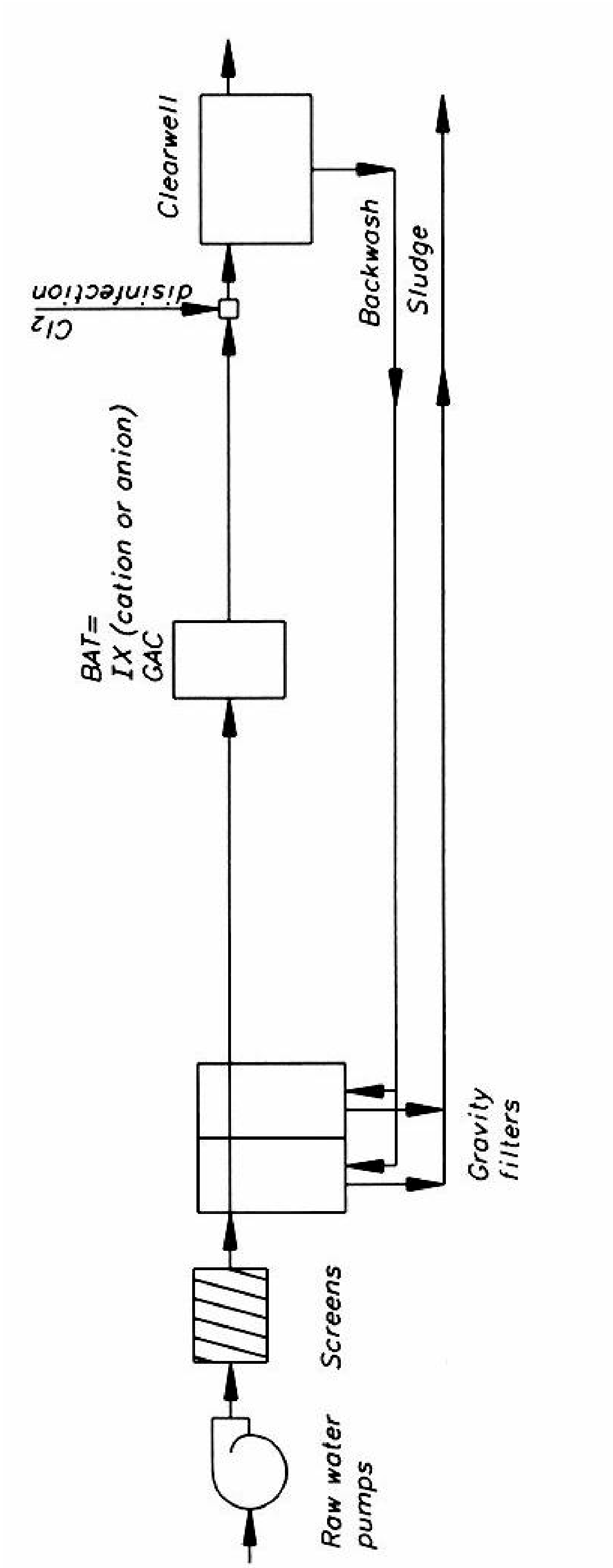
Waste Disposal - Backwash/flush water disposal is required if incorporated. Disposal of spend media is the responsibility of the contractor providing the media replacement services.

Advantages -
- ! Well established.
- ! Suitable for some organic chemicals, some pesticides, and THMs.
- ! Suitable for home use, typically inexpensive, with simple filter replacement requirements.
- ! Improves taste and smell; removes chlorine.

Disadvantages -
- ! Effectiveness is based on contaminant type, concentration, rate of water usage, and type of carbon used.
- ! Bacteria may grow on carbon surface.
- ! Adequate water flow and pressure required for backwashing/flushing.
- ! Requires careful monitoring.

TPC - $/1000 gal





Raw water pumps
Screens
Gravity filters
BAT=
IX (cation or anion)
GAC
Cl_2
disinfection
Clearwell
Backwash
Sludge

11. DF TPC

Process - Direct filtration uses the conventional chemical and physical treatment processes of chemical addition, rapid mix, coagulation with dry alum, flocculation, and dual media filtration. Chemical coagulation and flocculation consists of adding a chemical coagulant combined with mechanical flocculation to allow fine suspended, and some dissolved solids to clump together (floc). $Al_2(SO_4)_3$ has been proven to be the most effective coagulant for asbestos removal. Filtration provides final removal by dual media filtering of all floc and suspended solids. In addition to the unit processes mentioned, the DF treatment train typically includes raw water pumps, debris screens, and clearwell storage.

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required.

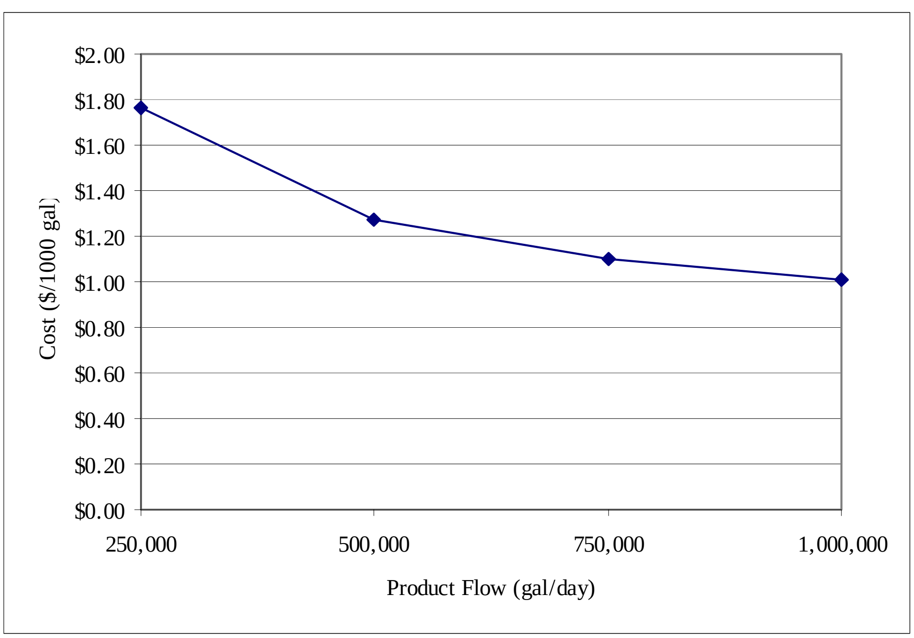
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Routine checks of contaminant buildup in the filter is required, as well as filter backwash. Recharging or clean installation of media is periodically required.

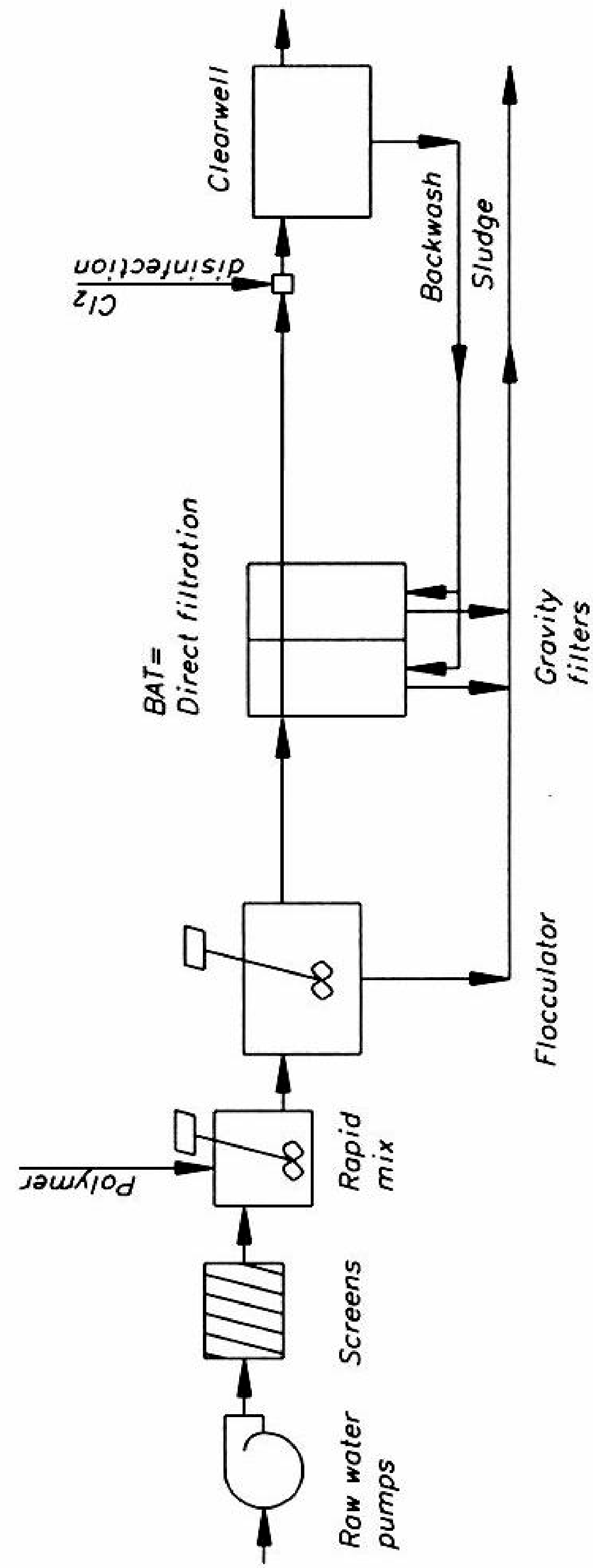
Waste Disposal - Filter backwash and spent media require approved disposal.

Advantages -
- ! Lowest capital costs.
- ! Lowest overall operating costs.
- ! Proven and reliable.
- ! Low pretreatment requirements.

Disadvantages -
- ! Operator care required with chemical handling.
- ! Produces high sludge volume.
- ! Waters high in sulfate may cause significant interference with removal efficiencies.

TPC - $/1000 gal




Raw water pumps
Screens
Polymer
Rapid mix
Flocculator
BAT= Direct filtration
Gravity filters
Cl_2 disinfection
Clearwell
Backwash
Sludge

12. MF TPC

Process - Microfiltration is a physical process and refers to filtration through a coherent medium with a nominal pore size range from slightly below 0.1 µm to slightly above 1.5 µm. This size range refers to the pore size of the medium itself. Thus, in terms of pore size, MF fills in the gap between ultrafiltration and granular media filtration. In terms of characteristic particle size, this range covers the lower portion of the conventional clays and the upper half of the range for humic acids. This is smaller than the size range for bacteria, algae and cysts, and larger than that of viruses. Similar to RO, the raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Unlike RO, lower hydraulic pressures are required. MF membranes includes both crossflow separation and dead-end filtration. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Factors influencing performance are raw water characteristics, pressure, temperature, and regular monitoring and maintenance. The DF treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an polymer, slow mix flocculator, MF membranes, chlorine disinfection, and clearwell storage.

Pretreatment - Jar tests to determine optimum polymer addition may be required.

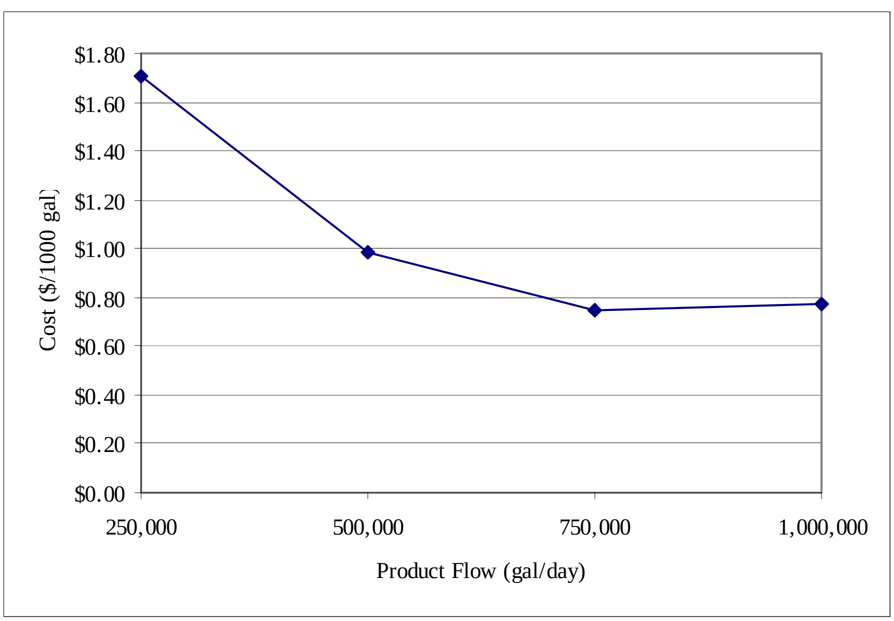
Maintenance - Monitor rejection percentage to ensure contaminant removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

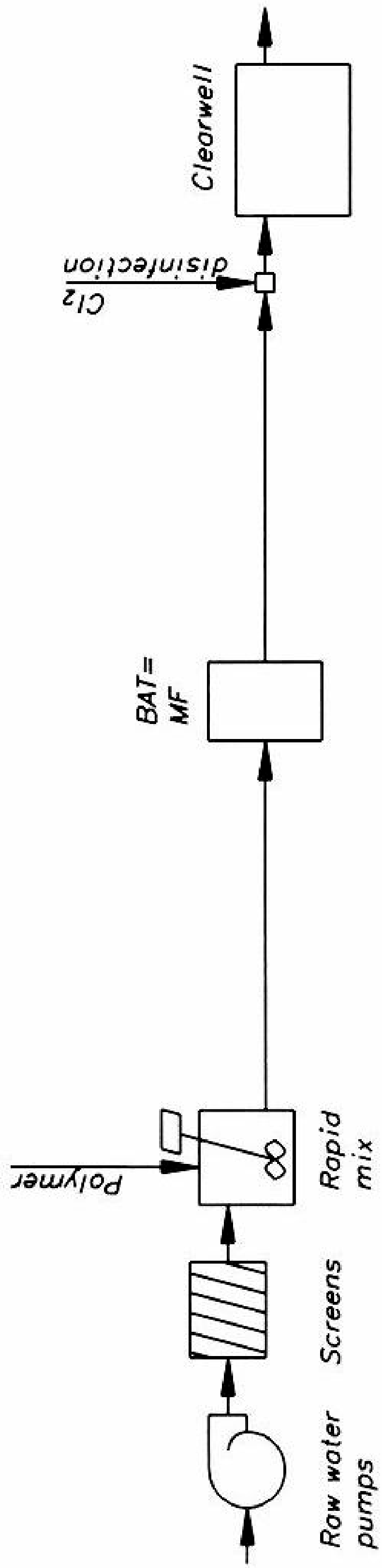
Waste Disposal - Pretreatment waste streams, concentrate flows, and spent filters and membrane elements all require approved disposal.

Advantages -
- ! Low pressure process.
- ! Can typically produce water of satisfactory turbidity with feed waters exceeding 100 NTU.
- ! *Giardia* removal as high as 6 logs is reported. Bacteria removal is satisfactorily high. *Cryptosporidium* is satisfactory. Virus removal of 0.5 log (68 percent).
- ! Disinfection byproduct removal is about 10 percent.

Disadvantages -
- ! Membrane integrity and testing protocols are still under development.
- ! Some regulatory agencies slow to accept MF applications.

TPC - $/1000 gal




Raw water pumps
Screens
Rapid mix
Polymer
BAT= MF
Cl2 disinfection
Clearwell